A new bio-geomorphic model approach accounting for subgrid-scale heterogeneity of biogenic structures

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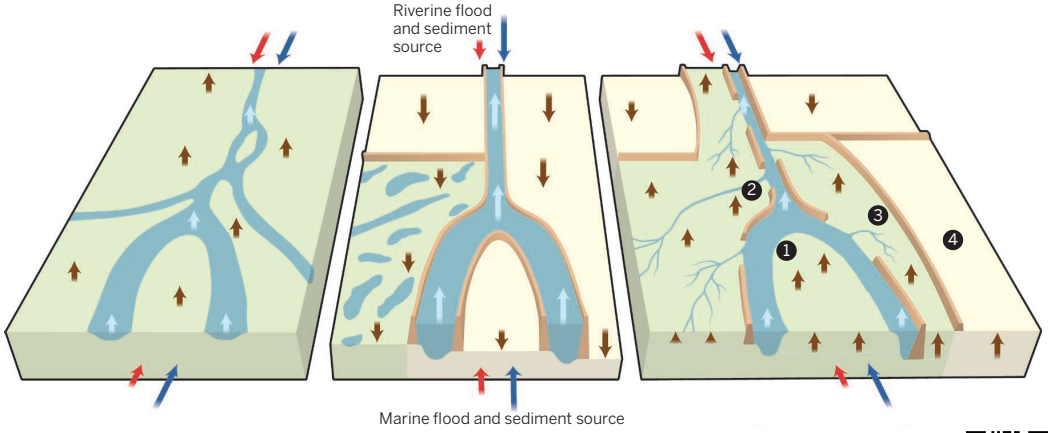
Tidal marshes provide important ecosystem services

1. Carbon sequestration
   $\rightarrow$ among highest rates of all natural systems
2. Natural coastal protection
   $\rightarrow$ storm surges, wave erosion
3. Water quality improvement
4. Important habitat for commercial fisheries

Tidal marsh conversion to human land use and restoration

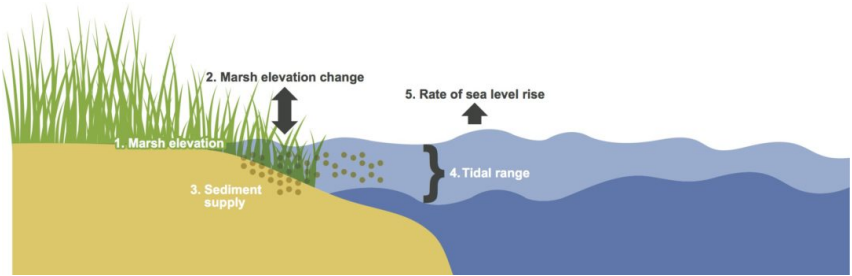


Temmerman and Kirwan (2015).
Building land with a rising sea. *Science*.

Tidal marshes are threatened by climate/environmental changes

Capacity to build up with sea level rise limited by

- rate of sea level rise
- availability of sediments
- capacity of vegetation to trap sediments



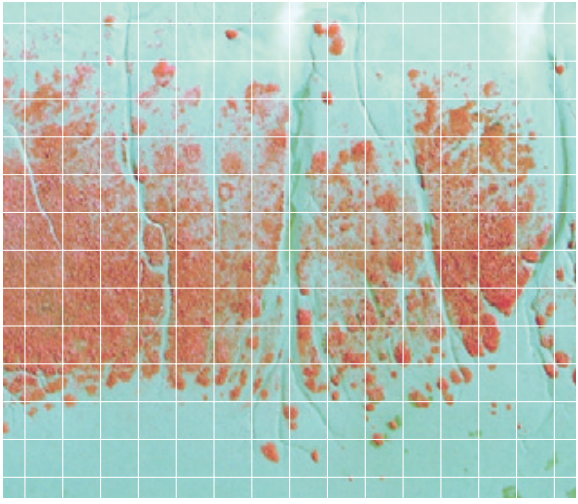
Elementary bio-geomorphic feedbacks in tidal marshes

Vegetation induces friction

→ flow attenuation

→ sediment accretion

Vegetation-induced friction in bio-geomorphic models



Classical approach

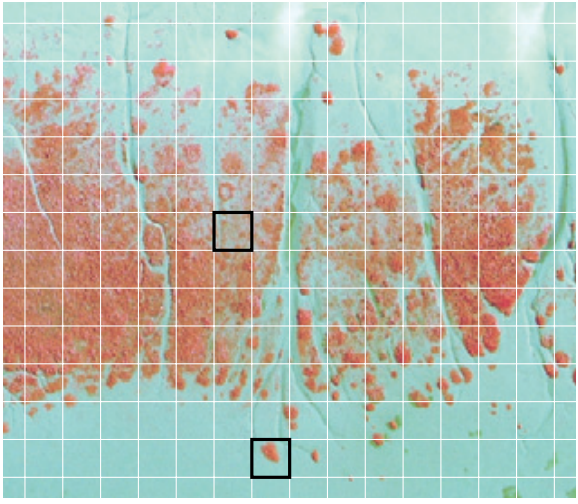
→ averaged biomass (only)

New approach

→ averaged biomass

→ vegetation heterogeneity (subgrid-scale)

Vegetation-induced friction in bio-geomorphic models



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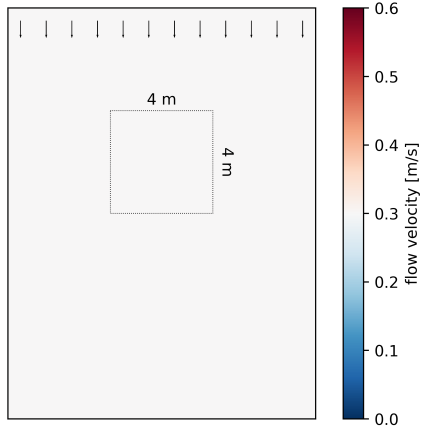

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Flow attenuation: $\boxed{Q'_{-} = 1 - \frac{Q}{Q_0}}$

Q discharge through patch

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$\rightarrow$ relative discharge not going through vegetation

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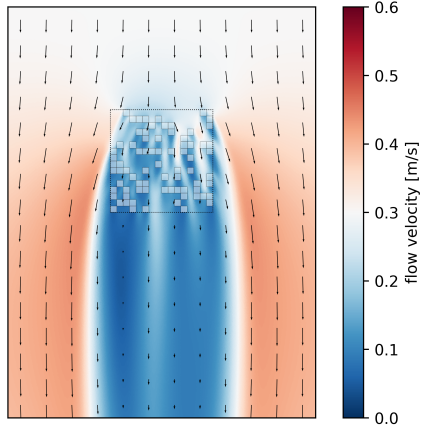
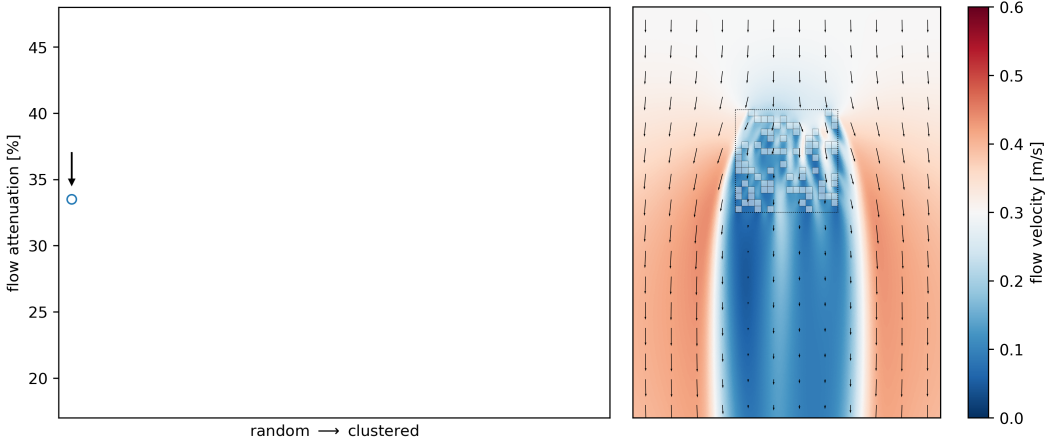


Flow attenuation decreases with vegetation clustering



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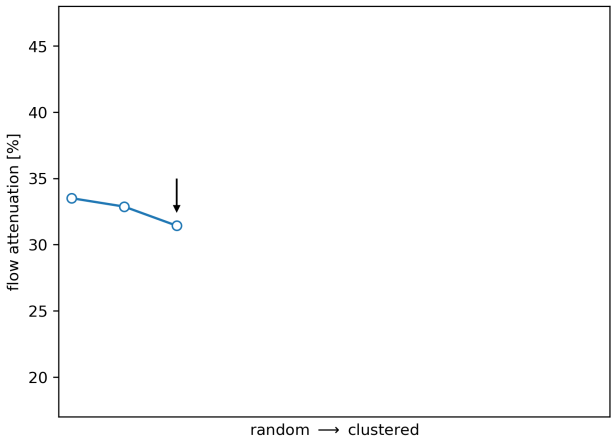

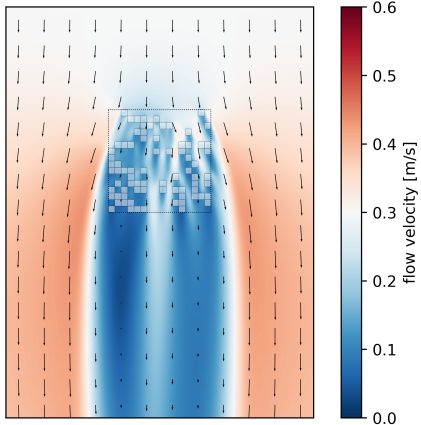

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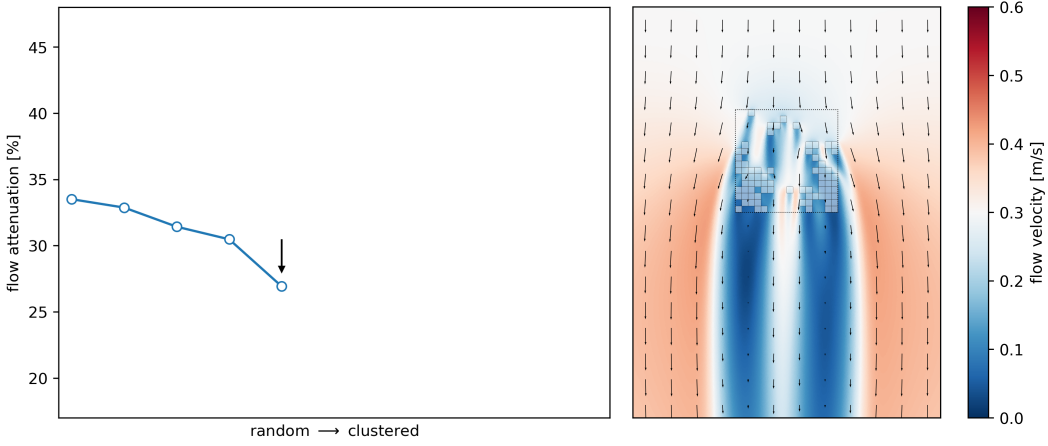

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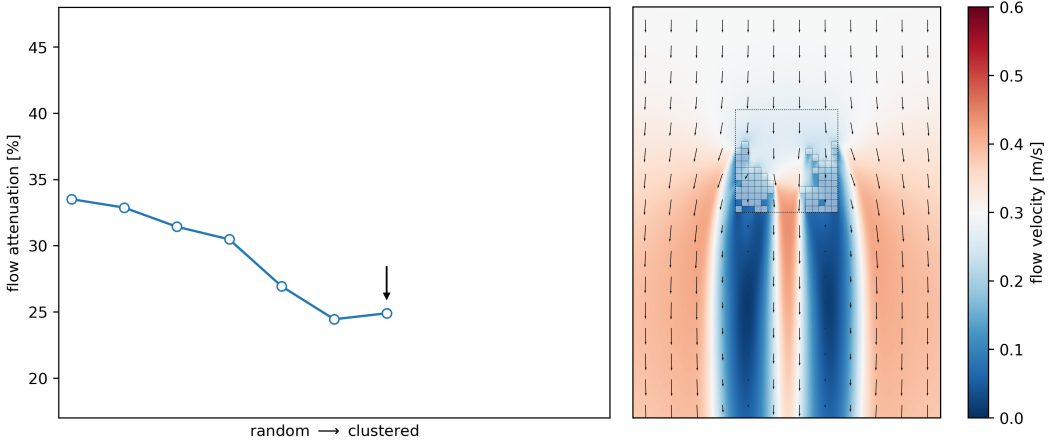

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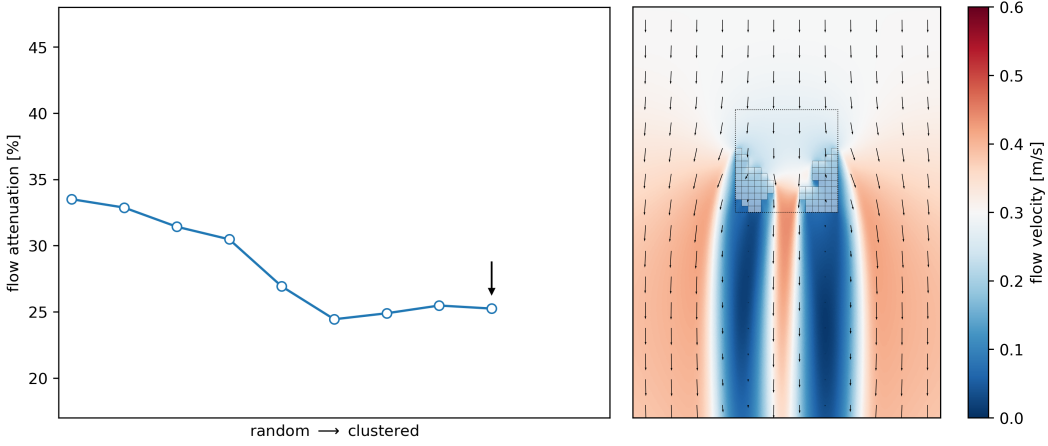

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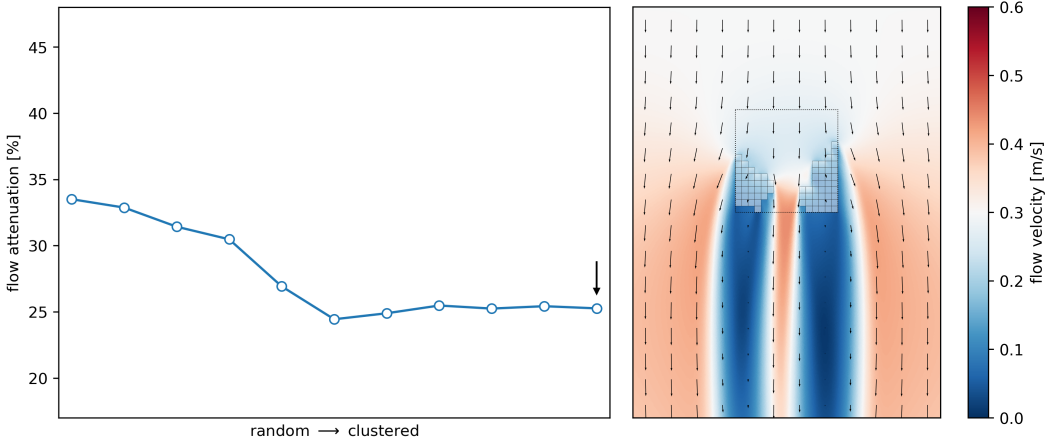
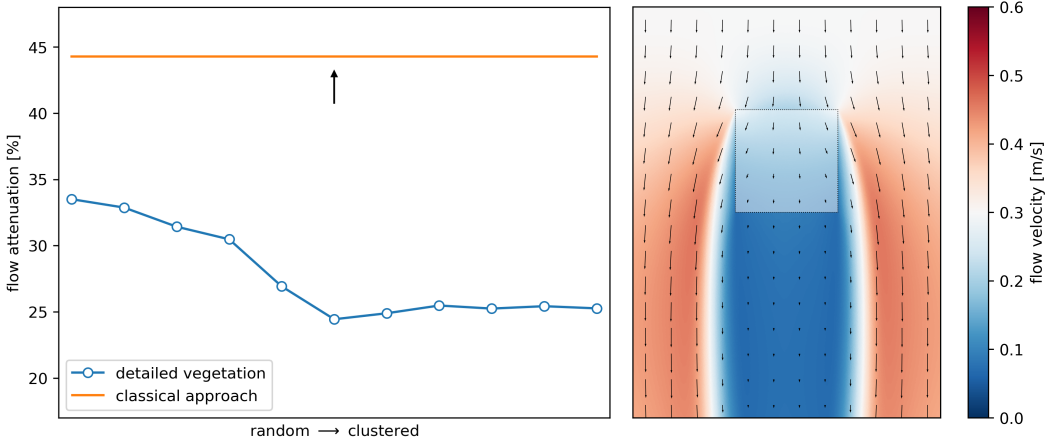


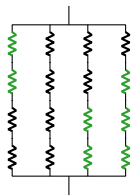
Classical approach overestimates flow attenuation



Electronic circuit analogy

Ohm's law: $\boxed{U = RI}$

U	electric potential
I	electric current
R	electric resistance

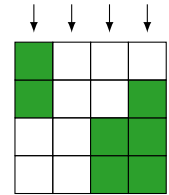


In series: $R_{eq} = R_1 + R_2 + \cdots$

In parallel: $\dfrac{1}{R_{eq}} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \cdots$

Chézy formula: $\boxed{\sqrt{hi} = \dfrac{1}{C} v}$

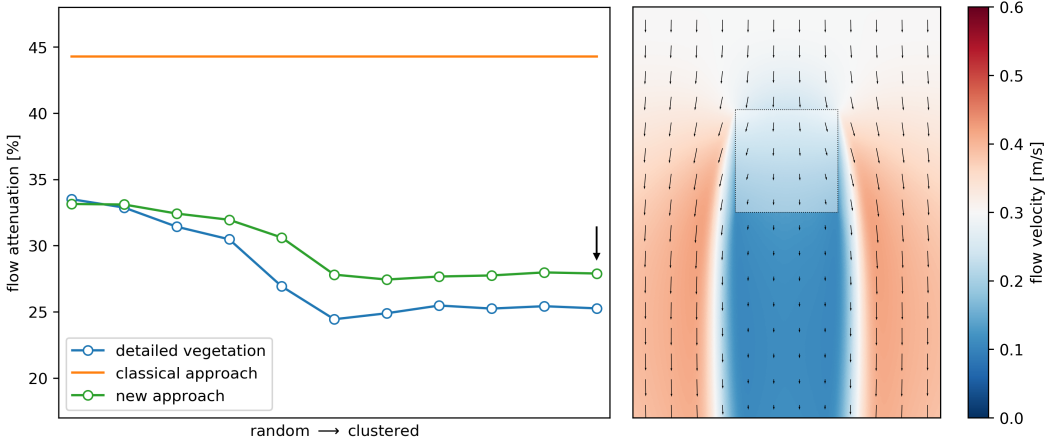
$\sqrt{hi}$	flow potential
v	flow velocity
$1/C$	flow resistance (friction)



Along-flow: $\dfrac{1}{C_{eq}} = \dfrac{1}{C_1} + \dfrac{1}{C_2} + \cdots$

Cross-flow: $C_{eq} = C_1 + C_2 + \cdots$

New approach simulates flow attenuation better



Marsh restoration project at the Belgian/Dutch border

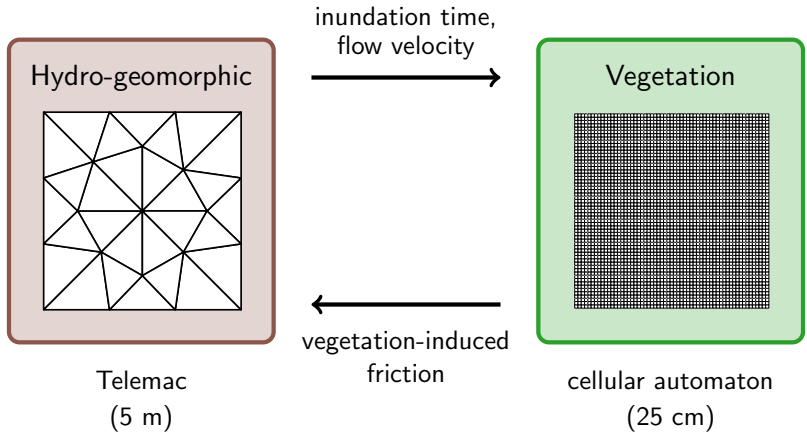
Hedwige and Prosper Polder

Stijn Temmerman, et al.

A bio-geomorphic model for smart design of climate resilient tidal marsh restoration

Thursday – 16:15 – Room G2

Demeter: new bio-geomorphic modeling framework



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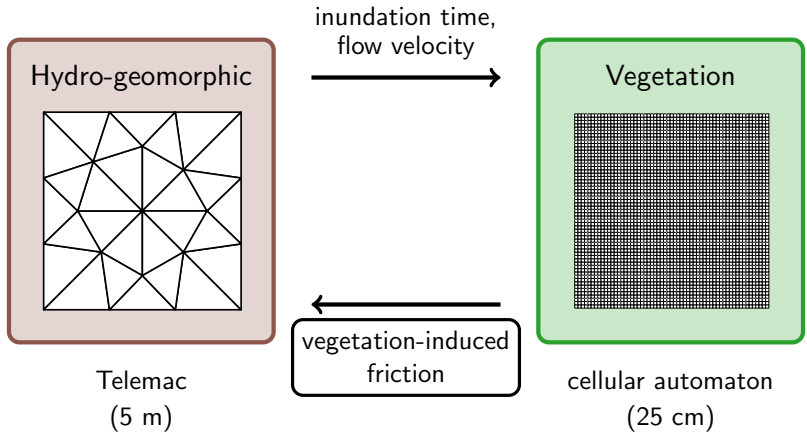
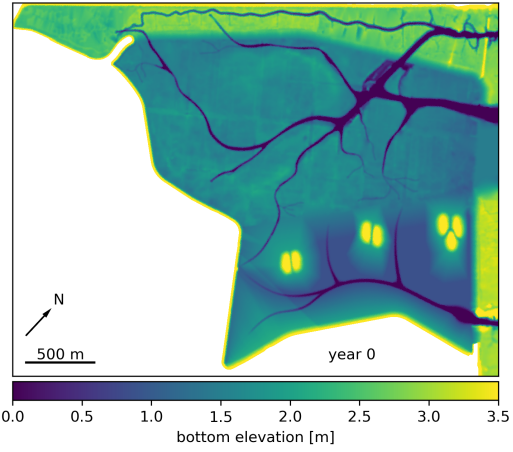
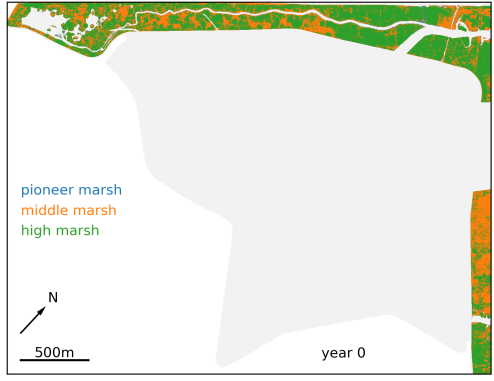


Landscape-scale long-term simulation





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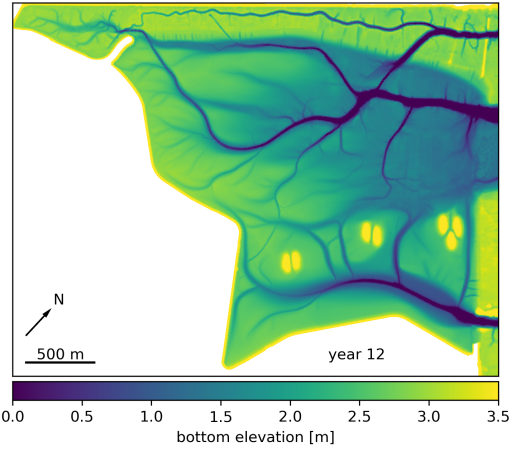

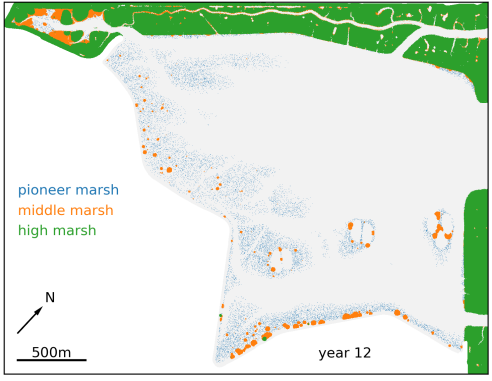

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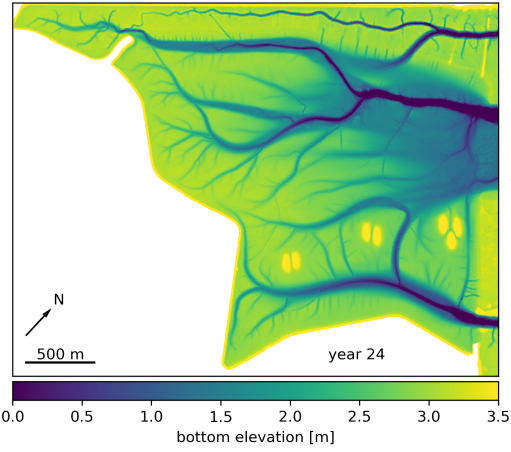

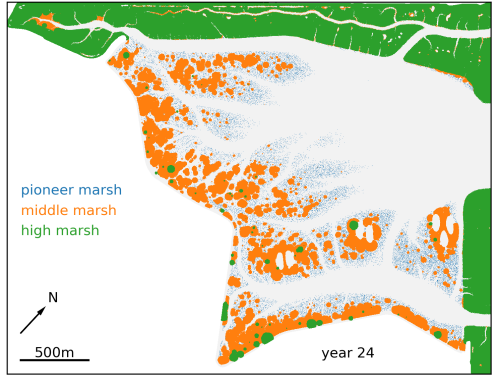

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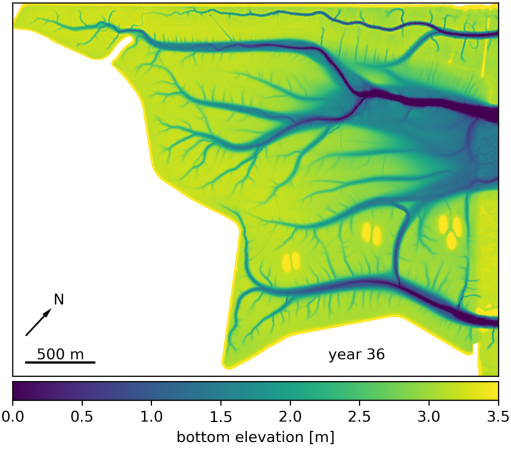

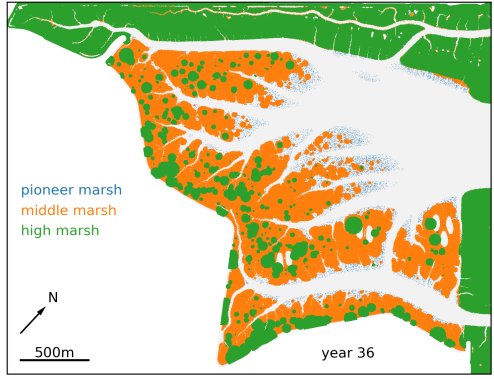

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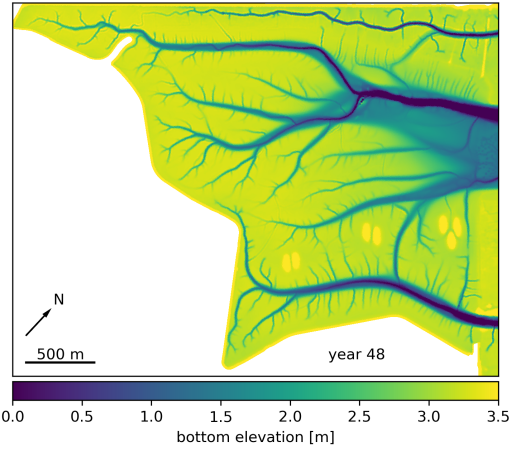
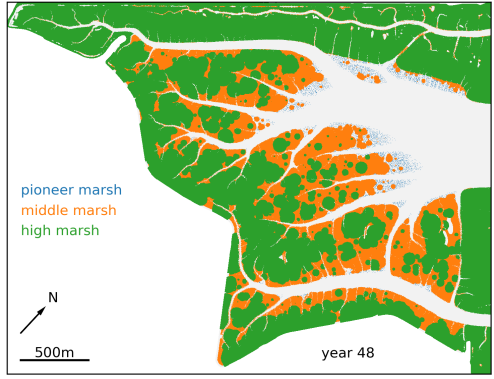
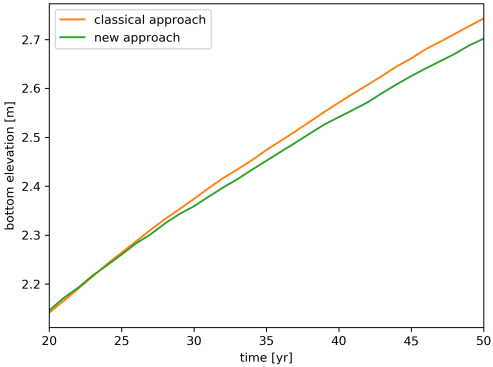
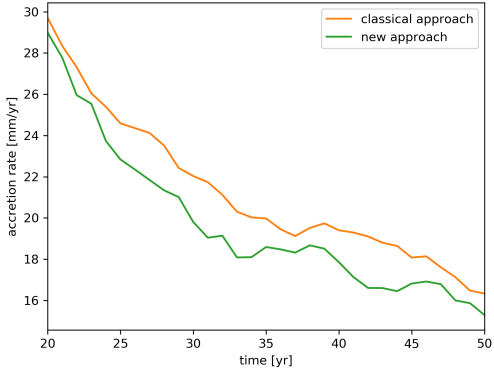




Lower accretion rates

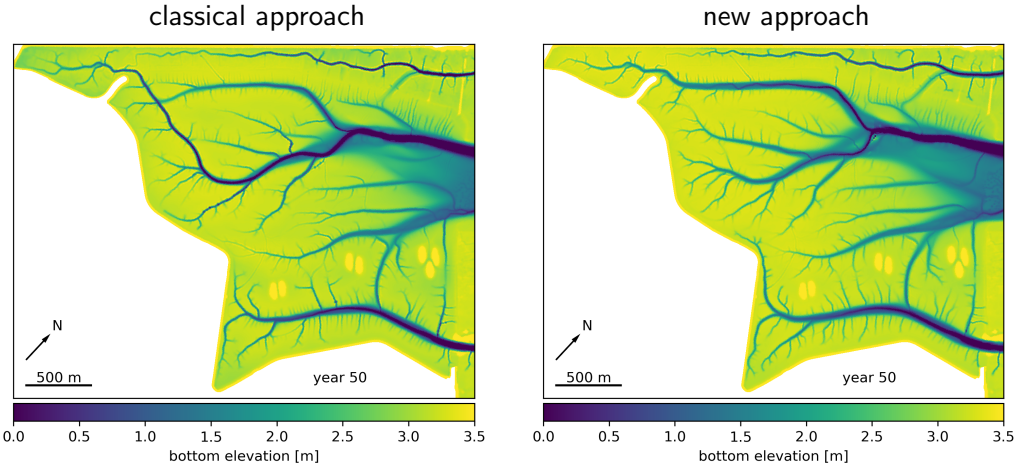
with new subgrid friction approach





Wider and shallower channels

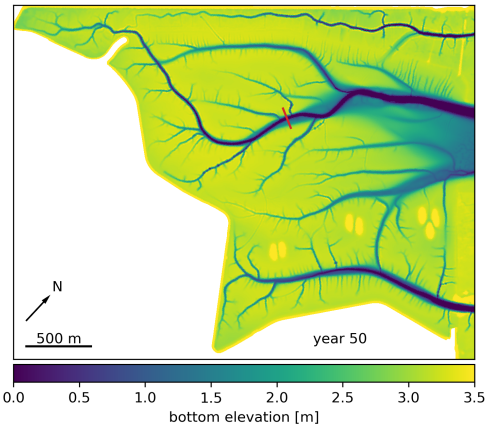
with new subgrid friction approach



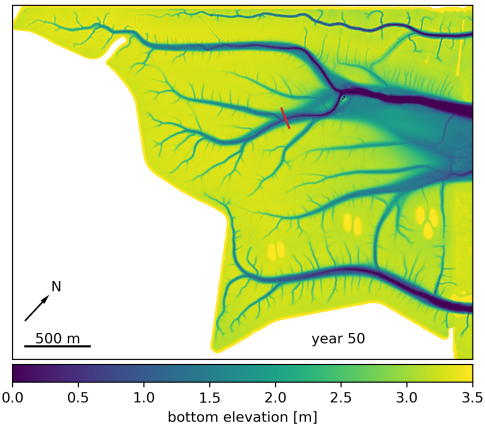
Wider and shallower channels

with new subgrid friction approach

classical approach



new approach



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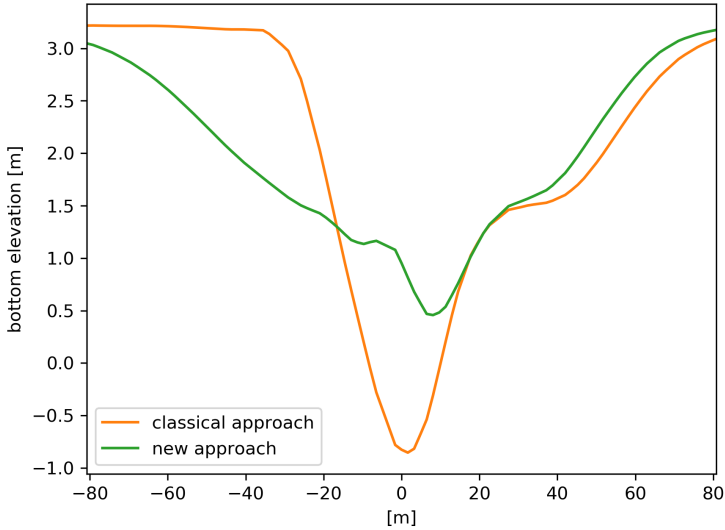


Take-home messages

1. Friction decreases with vegetation clustering
   → classical subgrid approach overestimates friction

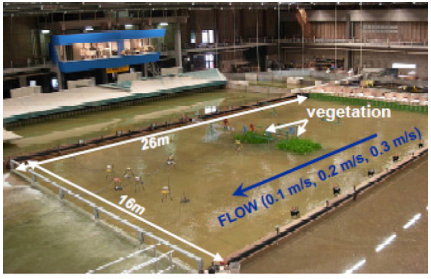
2. Our new approach allows for better estimation of subgrid friction
   → extra computational cost very low!
   → impact on accretion rates at landscape-scale

3. Our new approach suggests that tidal marshes are more vulnerable to sea level rise

Extra slides

A numerical model validated against flume measurements

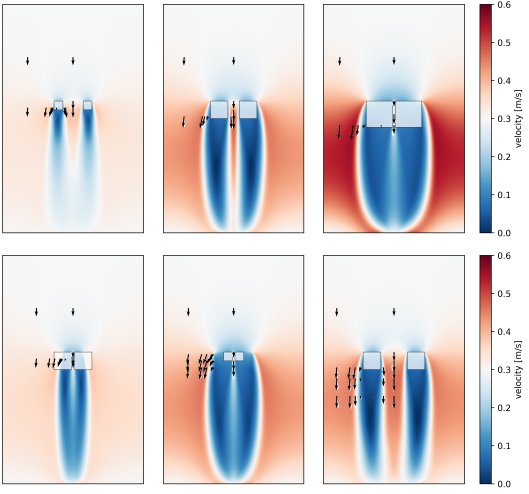
Flume experiment



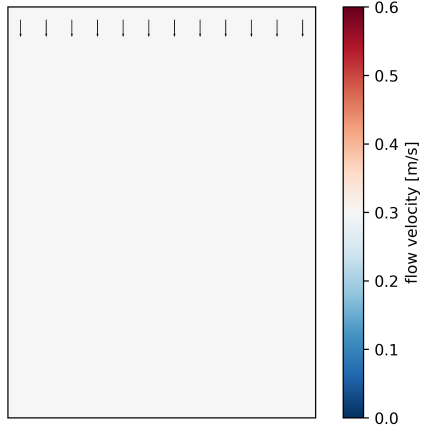
Vandenbruwaene, et al. (2011). Flow interaction with dynamic vegetation patches. *Journal of Geophysical Research*.

Bouma, et al. (2013). Organism traits determine the strength of scale-dependent bio-geomorphic feedbacks. *Geomorphology*.

Numerical model



A numerical experiment to quantify subgrid-scale friction



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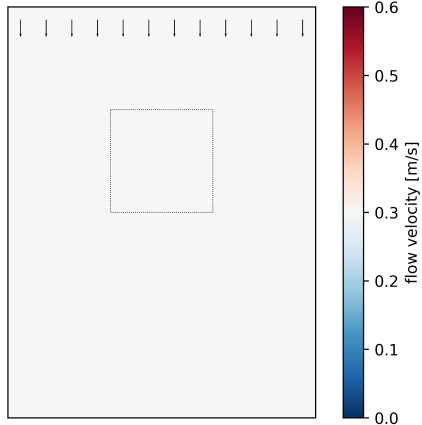

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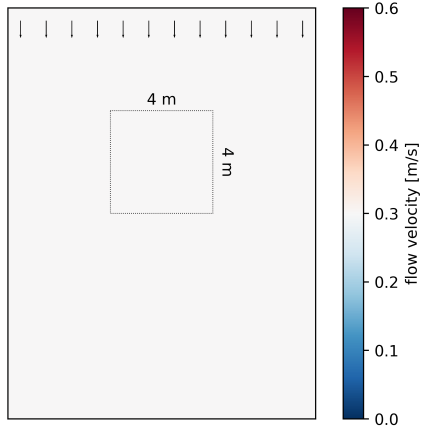

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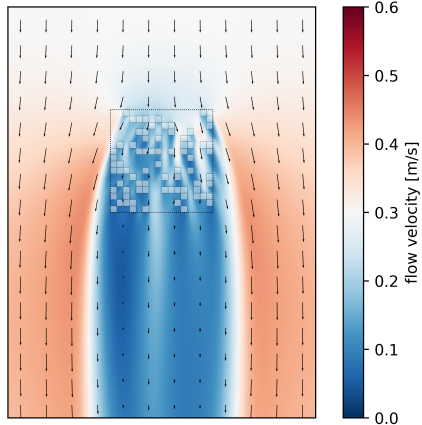

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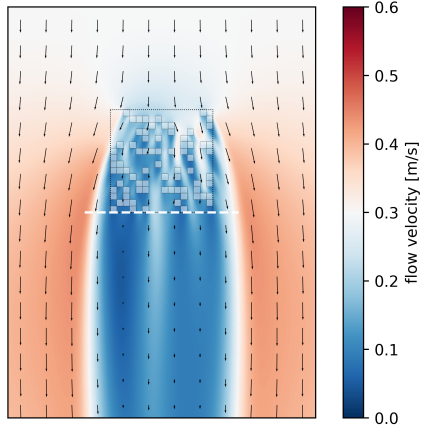

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